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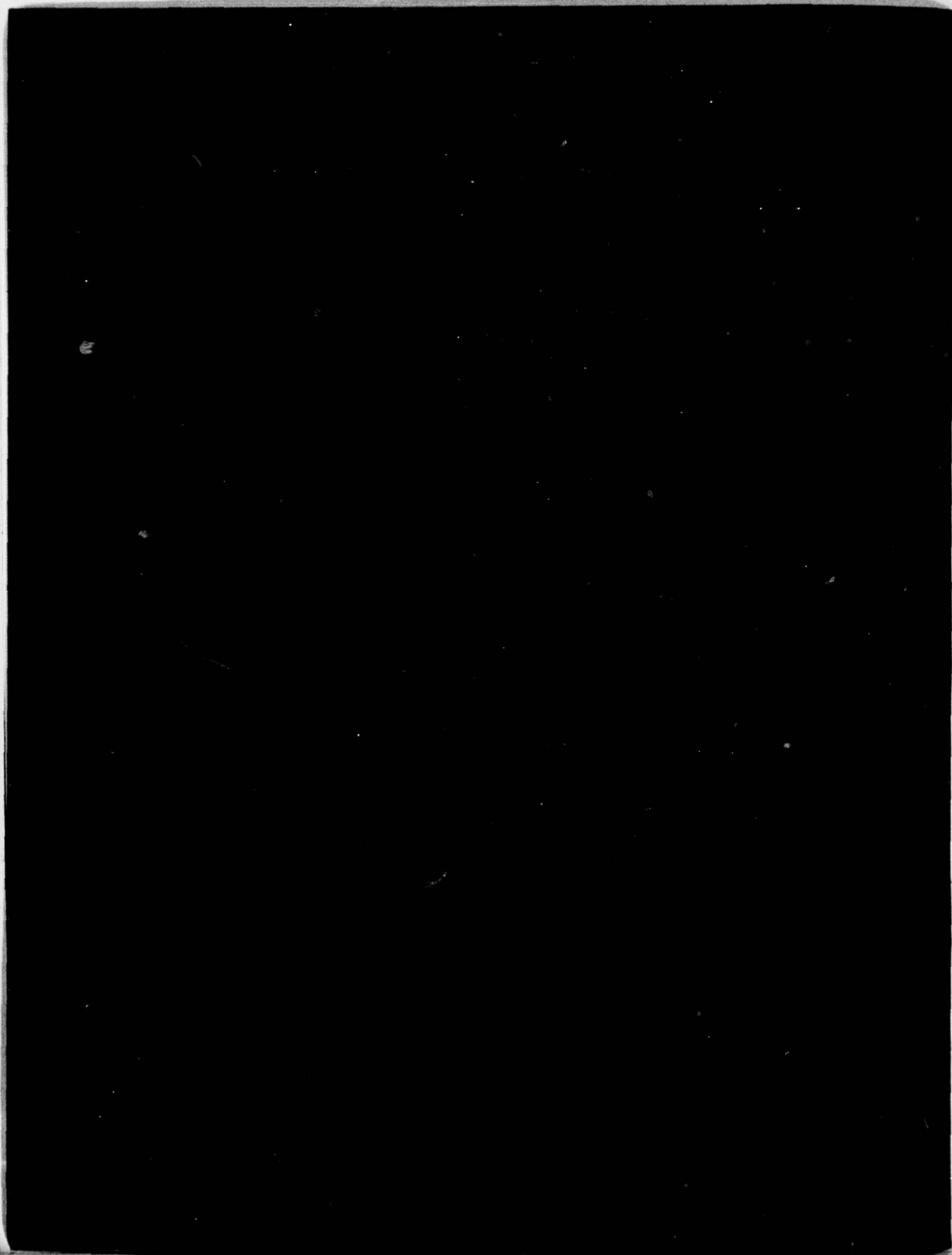
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16. Abstract ⑭ ATC-83-VOL-1 ⑮ FAA/RD ⑯ 78/33-VOL-1 Airborne measurements of the Air Traffic Control Radar Beacon System (ATCRBS) 1030 MHz uplink environment due to ATC ground interrogators are described. The measurements were made using a special purpose airborne sensor-recorder during a flight from Boston to Washington (at 8500 feet) and back (at 17,500 feet) on 16 December 1977. Data were recorded at 24 locations between Boston and Washington and processed to obtain distributions of pulse, interrogation, and suppression rates with received power. The most numerous contributors to the uplink pulse environment are omnidirectionally radiated suppression pulses. The overall average suppression rate is approximately 600 per second. The suppression rate is relatively independent of altitude but there are wide variations in the suppression rate from one location to another. Interrogation rates increase with altitude but do not vary significantly from location to location except near interrogators without sidelobe suppression. The overall average rate of receipt of Mode A plus Mode C interrogations is approximately 75 per second at an altitude of 8500 feet and 100 per second at an altitude of 17,500 feet. ⑫ 26 p. ⑰ Project Repts		
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1.0 INTRODUCTION

1.1 Purpose of Measurements

In-flight measurements of the Air Traffic Control Radar Beacon System (ATCRBS) uplink environment have been made for the FAA Airways Facilities Service to:

1. Statistically characterize the airborne interrogation environment in the northeastern part of the United States.
2. Locate and characterize the ground interrogators contributing to the measured airborne environment in the Northeast.
3. Measure the detailed radiation characteristics of selected ground interrogators.

These data will contribute to understanding and resolving existing ATCRBS interference and ATCRBS interrogator site coverage problems. They will also be used for defining the radiation environment in which beacon-related systems such as BCAS and DABS must operate in the future.

The measurements* were made along a flight path between Boston and Washington, D.C., using the Lincoln Laboratory Airborne Measurements Facility (AMF). This equipment** senses 1030 MHz pulses using a calibrated receiver with an angle of arrival antenna, and digitizes and records the received pulse amplitude and timing data along with other navigation data for subsequent processing. Processing software then decodes the interrogation modes and associates interrogations with originating interrogators by analysis of repetition intervals.

1.2 Organization of Report

Results of the data analysis are presented in two volumes:

1. Volume I reports the airborne interrogation environment observed at locations along the flight path with minimum regard to the sources of the received pulses. The environmental data include total event counts (pulses, suppressions, interrogations, number of interrogators seen) for all locations, and distributions of events vs. amplitude for selected locations.

* Similar measurements have previously been reported in "Uplink Coverage Measurements in the Los Angeles Area for Passive BCAS," F. Nagy, Jr., Project Report ATC-81, Lincoln Laboratory, M.I.T. (7 November 1977), FAA-RD-77-134.

** The AMF is described in "The Airborne Measurements Facility (AMF) System Description," G. V. Colby, Project Report ATC-60, Lincoln Laboratory, M.I.T. (25 March 1976), FAA-RD-75-233.

2. Volume II reports the ground interrogator characteristics determined from the observed data.

These characteristics include the approximate locations of all observed interrogators as well as measured characteristics such as PRF, scan period, mode interlace, and for selected interrogators, radiated P1, P2, and P3 levels in the form of antenna pattern plots.

1.3 Description of the Flight Path

The airborne measurements were obtained during a round trip flight between Boston and Washington on 16 December 1977. These measurements were made at the 24 points shown on the map in Fig. 1-1. Data were recorded on a sampling basis over a period of one minute out of every ten throughout the flight. Thus the measurement segments were not intentionally related to specific cities, air terminals or interrogators. (The 24 chronologically ordered data locations are identified alphabetically from A through X.) The ground speed of the aircraft carrying the AMF varied from roughly 150 knots on the low-altitude leg to a maximum of 240 knots on the high-altitude return leg. Thus these segments of one-minute recordings are about 25 to 40 nmi apart, and each segment is 2.5 to 4 nmi long.

The route to Washington, flown at an altitude of 8500 feet, was separated from the route back, flown at 17,500 feet, by about 30 nmi.

Fig. 1-1 also shows the locations of FAA and other (mostly military) interrogators along the flight route as obtained from a 5 January 1978 edition of the unclassified ECAC file.

1.4 Recording and Processing of Measurements

The beacon uplink environment consists of interrogation pulses (P1 and P3) and sidelobe or suppression pulses (P2) originating from FAA and military interrogators. In addition, pulse energy is transmitted from TACAN equipment operating at or near the 1030 MHz band. The AMF records the level, time of arrival and duration of each pulse whose amplitude exceeds a pre-selected threshold (generally set at -76 dBm) for at least 375 nsec, provided its leading edge rises at least 6 dB in an interval of 125 nsec. An estimate of the relative bearing of the source of each pulse is also recorded. All data included in this report were obtained from an antenna mounted on the underside of a twin-engine Piper Navajo aircraft. The pulse information is digitized with 1 dB resolution and recorded, together with aircraft position and time of day data, for later analysis.

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The AMF uplink analysis program a) associates the valid pulses into ATCRBS interrogation modes and suppression pairs; b) provides amplitude distributions and total event counts for each mode; c) arranges the interrogations into a time-ordered interrogation file; d) calculates all interrogation repetition intervals (PRI's) present in the interrogation data; and e) associates all interrogations from a given interrogator, thereby permitting identification of interrogator dwell time, beamwidth and scan period. The mode interlace pattern of the interrogator is also determined, and deviations of the actual time of occurrence of the interrogations from the expected time are calculated.

This volume summarizes the findings of the first two steps (a and b) of this analysis process. It also includes the total number of interrogators detectable at each location along the route (from step d). The results of the remaining steps in the uplink analysis are reported in the second volume.

2.0 RESULTS

This section presents five types of data:

1. Counts of the received event rates for individual pulses, interrogations and suppressions for the 24 measurement locations along the route.
2. A density distribution of the received interrogation rates vs. received signal level for one measurement location.
3. Cumulative distributions of the received interrogation rates vs. received signal level for five measurement locations.
4. A count of the number of interrogators detected at each measurement location along the route.
5. Histograms of the number of interrogators detected for each peak mainbeam pulse amplitude level at six measurement locations.

2.1 Event Rates and Interrogator Counts for Each Measurement Location

Received event rates are plotted in Fig. 2-1 for the 24 measurement locations along the route.

The following event rates are plotted:

- Total pulse rate
- Suppression rate
- Mode A interrogation rate
- Mode C interrogation rate
- Mode 1 interrogation rate
- Mode 2 interrogation rate

These event rates are 60-second averages of all events recorded above a level of -73 dBm referred to the antenna end of the AMF transmission line. As such, they represent the average event rates which would be seen by an ATCRBS transponder with sensitivity at the midpoint of the sensitivity limits allowed by the ATCRBS National Standard.

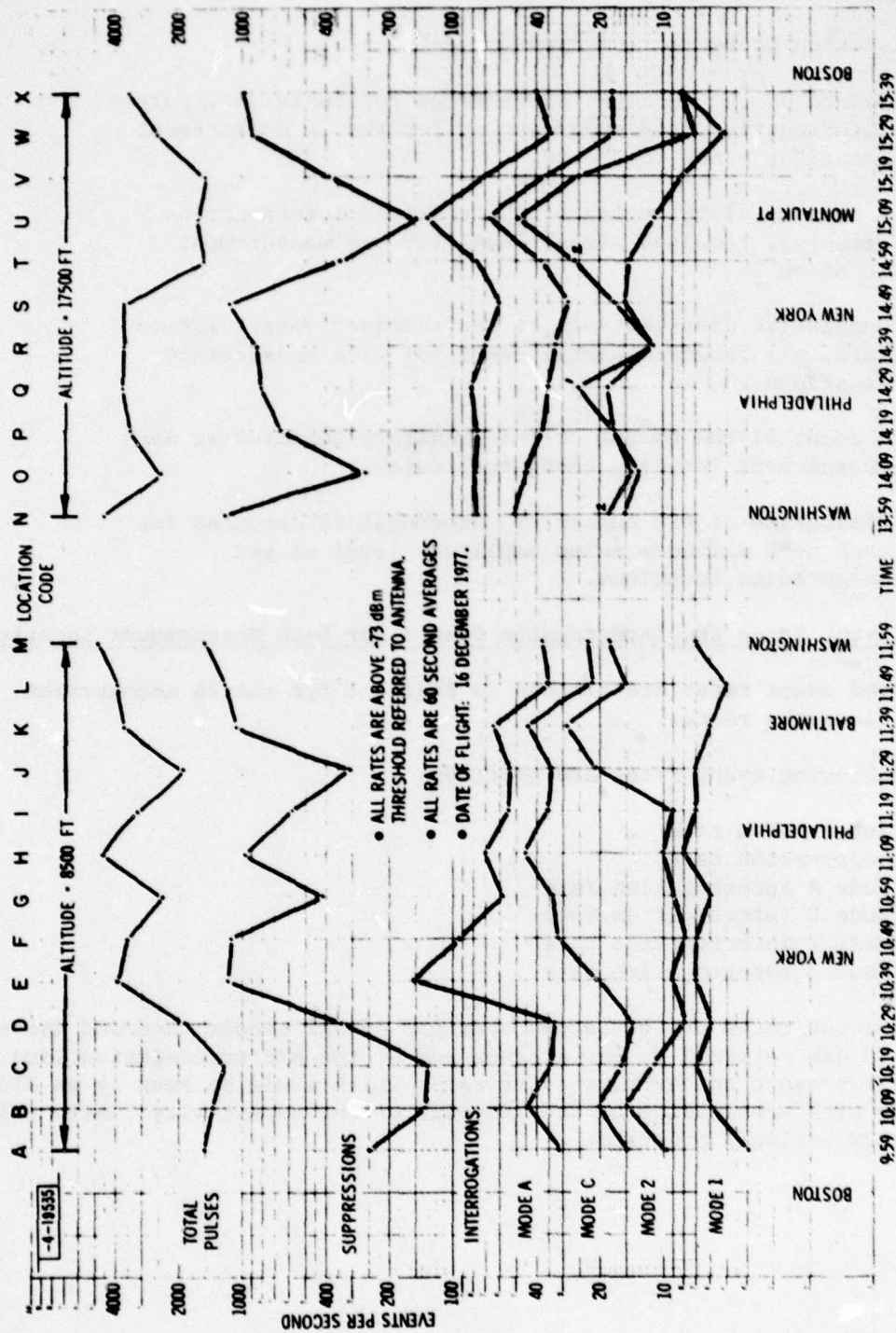


Fig.2-1. Received event rates at each flight path measurement location.

The total pulse rate (T) along the route varies from 1200 to 4000 pulses per second. In most locations, the rate of receipt of P1 - P2 suppression pairs is the single dominant contributor to the total pulse rate. In addition to pulses associated with suppressions and interrogations, the total pulse rate includes a very large contribution from single pulses which are not decoded as belonging either to interrogations or suppressions by the uplink analysis program. These are primarily individual P2 suppression pulses transmitted from omnidirectional antennas.

Other less important contributors to the total count include a) TACAN pulses both from ground-based and airborne TACAN transmissions at frequencies in the vicinity of 1030 MHz (provided they satisfy the rise-time criterion for acceptance by the AMF), b) military Mode-4 interrogation pulses, and c) multipath reflections of all of these pulses.

The suppression rates experience large variations along the route. This is to be expected since suppression pulses from a 1-Kw peak power transmitter are not detectable beyond a range of 10 to 30 nmi and many interrogators transmit at considerably lower peak power. Since the measurements are separated by up to 40 nmi there is no correlation between suppression environments from one site to the next. The 2-pulse suppression rates are roughly 3 times greater than 3-pulse suppression rates (3-pulse suppression counts include all decoded interrogations which include in the P2 position a valid pulse whose amplitude is not more than 4-dB below the amplitude of P1). The sum of the suppression rates ranges from 130 to 1500 per second, and the average over all locations is 612 per second. Since suppressions are generally transmitted by a single interrogator at rates of 300 to 400 per second, it is clear that there are not more than 4 or 5 interrogators within suppression range of any location.

Locations with relatively low suppression rates are B and C in Connecticut and O in Maryland. None of these locations is near a heavy local concentration of interrogators, although O has the highest overall interrogator count. Thus the suppression count is a good indicator of the immediate interrogator density around a measurement location, but is completely uncorrelated with the total number of interrogator mainbeams detectable from that location.

Mode A interrogations occur about twice as frequently as Mode C interrogations. This is consistent with the mode interlace pattern AAC of FAA terminal interrogators, and the pattern 2ACA of the FAA enroute interrogators. Military modes 1 and 2 always occur at lower rates than Modes A and C. Mode 1 and 2 rates are about equal, with one or the other predominating depending on the location and the time of day. Actual rates observed range from 32 to 160 Mode A's, 14 to 65 Mode C's, and 4 to 49 Mode 1's or 2's per second.

The pronounced peak in the Mode A rate at positions E and F (near NYC) appears to be due to a single interrogator without SLS located in the western part of Long Island somewhere east of JFK. This interrogator transmitted Mode A exclusively and was either searchlighting the AMF or was transmitting with an omnidirectional antenna. The Mode A transmissions were received at a level just above the MTL of the AMF (which would suggest an omnidirectional transmission). This interrogator was not detected at any location other than E and F, even though the return leg included one measurement location just to the east of JFK (location S). From this, it appears that the interrogator had been turned off in the four-hour interval between the out and back legs.

Another interrogation peak occurs at Montauk Point on the tip of Long Island (location U). The Montauk Point interrogator is a military interrogator transmitting a 2ACA mode interlace without sidelobe suppression. In flying by this site, the AMF detected nearly continuous interrogations in the sidelobes of the interrogator antenna. The resulting peaks in the Mode 2, A and C interrogation rates are pronounced. There is a corresponding reduction in the received suppression rate at this site since the Montauk Point interrogator does not transmit SLS pulses at all and it is at least 30 nmi from other interrogators which employ ISLS transmissions. Also contributing to the high interrogation rate at location U (as well as locations T and V) are two more interrogators without SLS, one at Orange, Connecticut, and the other somewhat to the north of Orange.

If these two unusual locations are discounted, the Mode A and C interrogation counts do not change significantly between consecutive measurements over the entire Northeastern coastal region. This is clearly because the detection range for these modes is large (50 to 200 nmi). There is a slight falloff in interrogation rates at the extremes of the Northeast corridor. This falloff is somewhat more pronounced at the lower altitude. It is not seen in the total pulse count because the total pulse count is dominated by short-range omnidirectional transmissions.

The average rate of receipt of Mode A and Mode C interrogations increased noticeably when the AMF altitude increased from 8500 to 17,500 feet. Altitude dependence is pronounced in the interrogator counts of Fig. 2-2. It is likely that this altitude dependence would have been even greater were it not for the fact that the low altitude leg was inland while the high altitude leg was directly along the coastline and was influenced only by interrogators to the west of the flight path.

2.2 Distributions of Event Counts with Received Power Level

The AMF detects and records all pulses which exceed a selected receiver threshold setting. Since the amplitude of each pulse is recorded to a resolution of 1 dB, it is possible to determine the distribution of the rate of receipt of pulses or interrogations at each amplitude above the receiver threshold. (The amplitude of an interrogation or suppression pair is taken as the amplitude of the smaller of the two pulses which make up the pair).

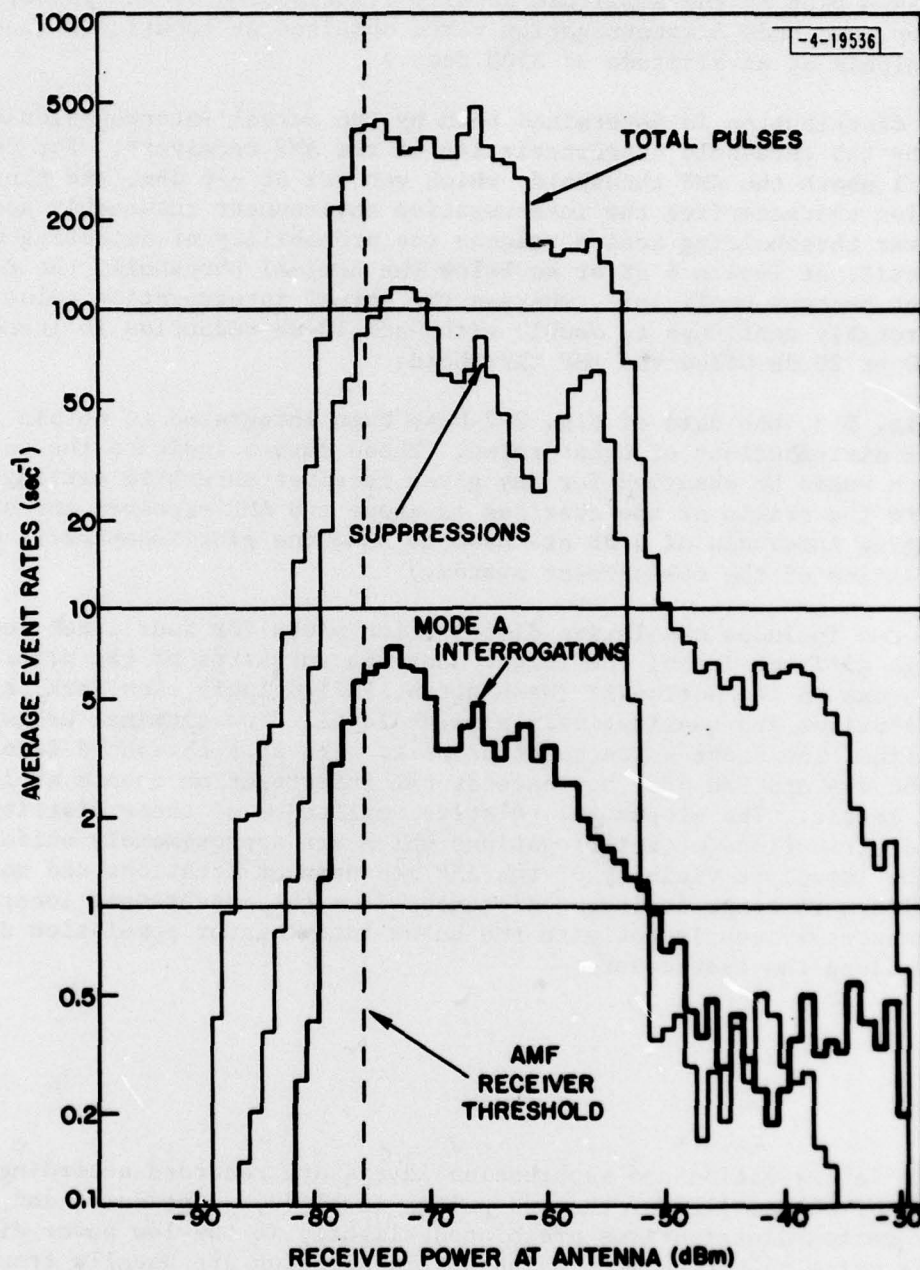


Fig.2-2. Distribution of received pulse, suppression, and Mode A interrogation rates with signal level for Location H, NE of Philadelphia (8500 ft. altitude).

Fig. 2-2 is a plot of the amplitude density distribution of the pulse, suppression, and Mode A interrogation rates obtained at location H (northeast of Philadelphia at an altitude of 8500 feet.)

This distribution is determined both by the actual interrogation environment and by the threshold characteristics of the AMF receiver*. For power levels well above the AMF threshold, which was set at -76 dBm, the plotted distribution characterizes the interrogation environment reasonably accurately. The receiver thresholding action reduces the probability of detecting weaker signals until, at levels 6 dB or so below the nominal threshold, the recorded reply count becomes negligible, whereas the actual interrogation pulse count in space roughly continues to double with each 10-dB reduction in level for another 10 or 20 dB below the AMF threshold.

In Fig. 2-3, the data of Fig. 2-2 have been integrated to obtain the cumulative distributions of event rates. These curves indicate the total rates which would be observed for any given receiver threshold setting. (In this figure the origin of the abscissa is above the AMF receiver threshold and averaging intervals of 5 dB are used to make the plot independent of the characteristics of the measurement system.)

Fig. 2-4 includes cumulative distribution plots for four other locations on the high altitude leg of the flight near the outskirts of the principal terminal areas in the Northeast (Washington, Philadelphia, New York, and Boston). The distributions are qualitatively similar in all four terminal areas. At each location, the suppression count drops to zero at a threshold level between -60 dBm and -50 dBm, but exceeds the interrogation counts at lower threshold levels. The slopes and relative amplitudes of these distributions indicate distributions of interrogations which are approximately uniform in area in the immediate vicinity of the AMF measurement locations and more nearly uniform in range at longer distances from the measurement location. This is reasonably consistent with the known interrogator population distribution along the east coast.

* Since interrogation and suppression levels are recorded according to the power of the smaller of the two pulses involved, suppression and interrogation distributions are biased slightly in the low power direction. Pulse pairs resulting from mainbeam transmission are usually transmitted with much less than 1 dB difference in pulse amplitude. Also, more than half of the suppressions are received from interrogators which use ISLS. Thus the average biases are probably less than -1 dB for interrogation and suppression curves.

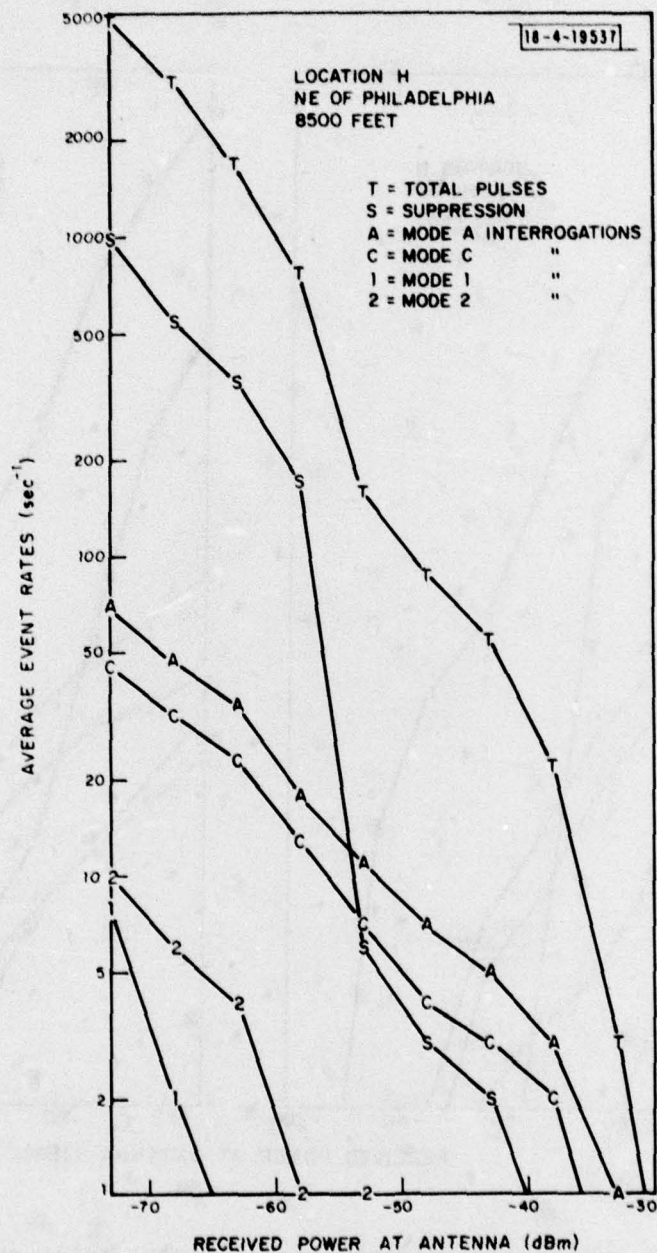


Fig.2-3. Cumulative distribution of event rates over received signal level for Location H, NE of Philadelphia (8500 ft altitude).

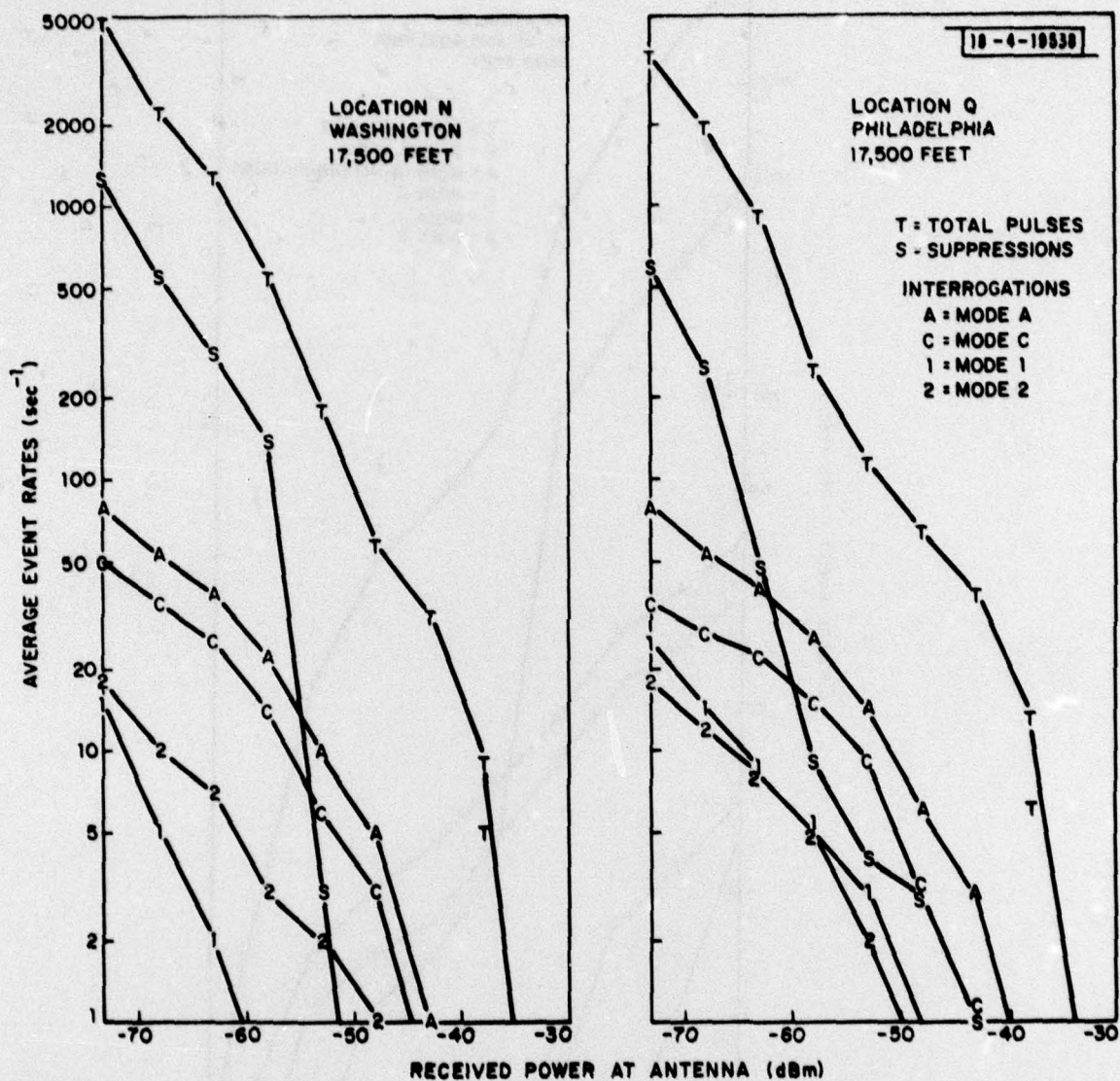


Fig.2-4. Cumulative distribution of event rates over received signal level for locations near the four major terminal areas.

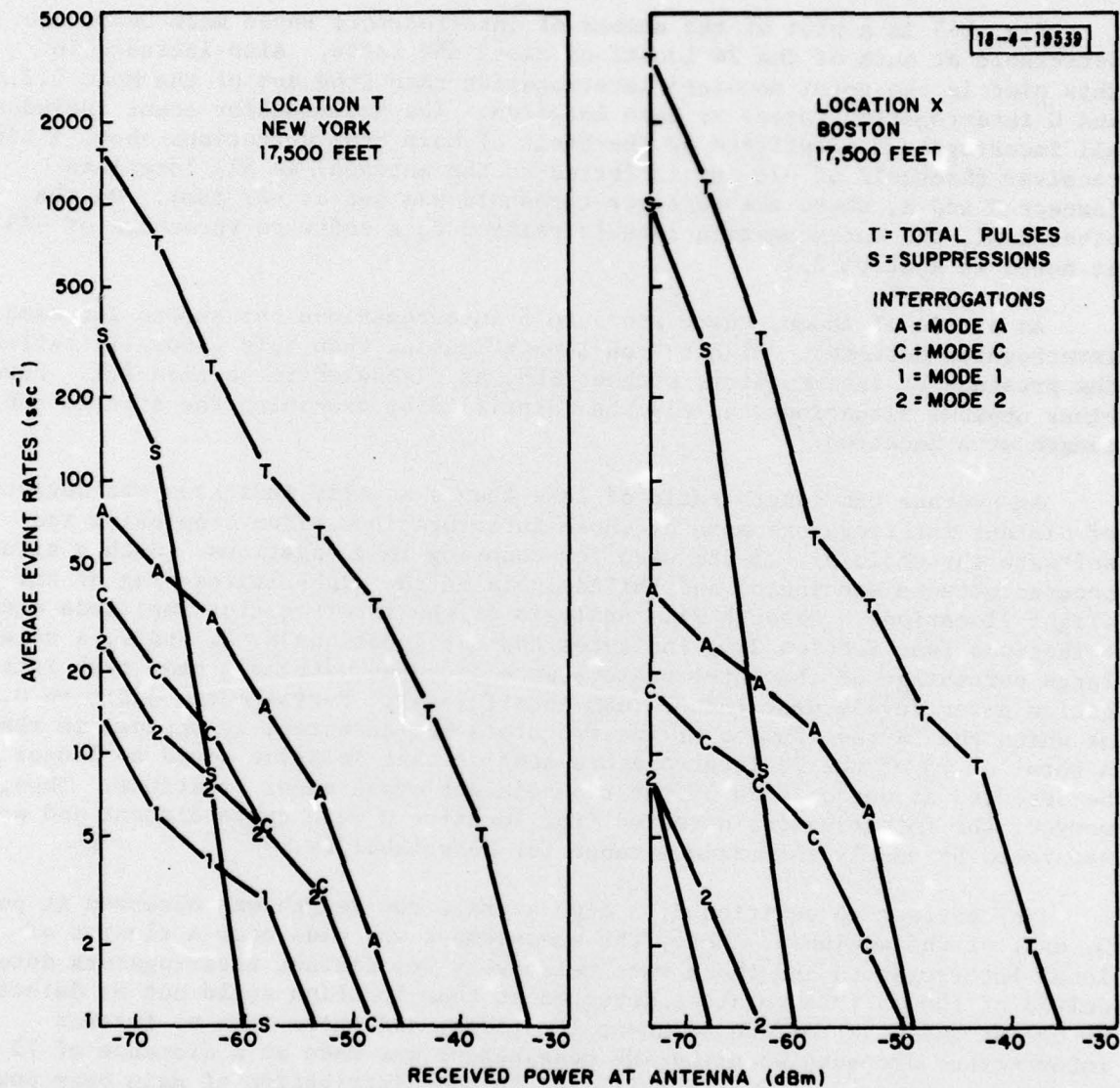


Fig.2-4. Continued

2.3 The Number of Interrogators Detected at Each Location

Fig. 2-5 is a plot of the number of interrogators whose main beams are detectable at each of the 24 locations along the route. Also included in this plot is the total combined interrogation rate (the sum of the Mode 1,2,A, and C interrogation rates) at each location. The interrogator count includes all interrogators identified on the basis of main beam detections above a fixed receiver threshold of -76 dBm (referred to the antenna) at all locations (except U and X, where the receiver threshold was set at -82 dBm). On the other hand, the interrogation rate is related to a software threshold of -73 dBm, as noted in section 2.1.

As a rule of thumb, there are 5 to 6 interrogations per second for each interrogator detected. Higher "run length" ratios than this generally reflect the presence of interrogators without SLS, as discussed in section 2.1. However, other unusual situations can also be identified by examining the average run length at a location.

An average run length ratio of less than 5 usually indicates the detection of distant interrogators some of whose interrogations often drop below the software threshold of -73 dBm used for counting interrogations. Such a situation occurred between Washington and Philadelphia on the high-altitude leg of the flight (locations N through P). Analysis of the interrogation amplitude distributions (see Section 2.4) indicates that at locations N, O, and P, a relatively large percentage of the interrogators were detected with main beam peak interrogation power levels near the -73 dBm cutoff level. Furthermore, position O, at which the largest number of interrogators was detected, is unusual in that a total of 13 of the 38 interrogators seen at that location could no longer be detected at one or both of the two adjacent measurement locations. Thus, many of the interrogators detected from location O were quite distant and were separated by nearly the maximum range for detectability.

In contrast to position O, a high average run length was observed at position Q, east of Philadelphia. Here, the measurement was made near a cluster of local interrogators and there were relatively few distant interrogators detected: only 3 of the 25 interrogators detected at that location could not be detected at one or the other of the adjacent locations, and there were no further interrogator dropouts when the AMF measurement was made at a distance of 75 nmi from location Q. This is reflected in the distribution of main beam power levels at this location: a relatively small percentage of the main beam peak interrogation power levels were recorded near the -73 dBm threshold. It is also noteworthy that almost all of the Washington-area interrogators detected at locations O and P had already dropped below threshold by the time the AMF reached location Q. The net result is relatively high average interrogation rate per interrogator detected at location Q.

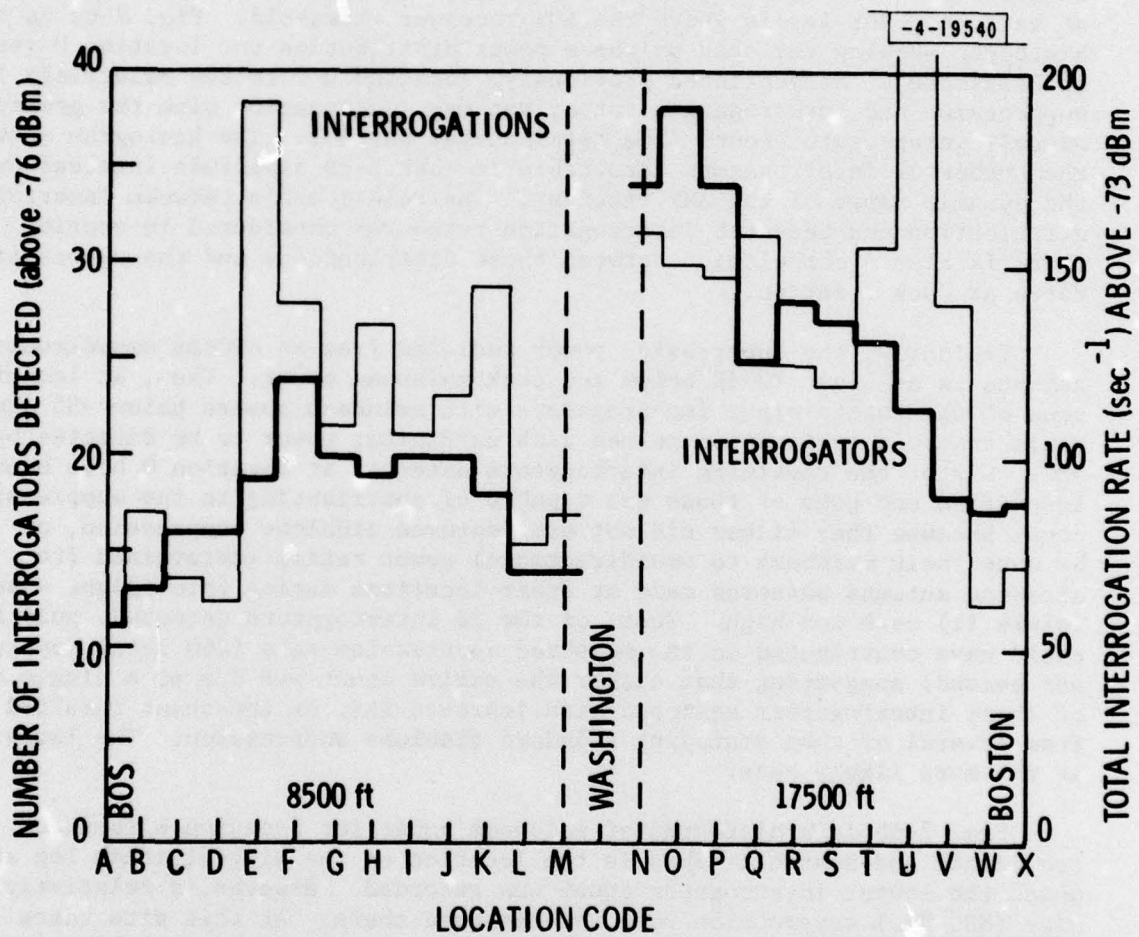


Fig.2-5. Number of interrogators detected at each location.

2.4 Distribution of Interrogator Counts with Peak Mainbeam Level

The distribution of interrogators in the vicinity of each measurement location can be further studied by plotting the number of interrogators detected at various power levels above the AMF receiver threshold. Fig. 2-6a is a histogram showing the peak mainbeam power distribution for location O (east of Baltimore). As mentioned previously, location O recorded relatively low suppression and interrogation rates, yet was the location with the greatest overall interrogator count (the total number was 39). The histogram shows the number of interrogators detectable in each 5-dB amplitude interval over the dynamic range of the AMF receiver. The relationship between interrogator distribution and measured interrogation rates was considered in section 2.3. There is also a correlation between these distributions and the suppression rates at each location.

Typically, the suppression power radiated from an ATCRBS omnidirectional antenna is at least 20 dB below the peak mainbeam power. Thus, at location O none of the twenty-eight interrogators with mainbeam powers below -55 dBm could transmit suppression pulses with sufficient power to be detected by the AMF. Six of the remaining interrogators detected at location O have been identified and none of those was capable of contributing to the suppression count because they either did not use improved sidelobe suppression, or because their mainbeam to omnidirectional power ratios (determined from airborne antenna patterns made at other locations during this flight - see Volume II) were too high. Thus, of the 39 interrogators detected, only five could have contributed to the measured suppression rate (260 total suppressions per second) suggesting that either the entire count was due to a single one of these interrogators equipped with improved SLS, or the count resulted from several of them employing standard sidelobe suppression. The latter is the more likely case.

Fig. 2-6b is a histogram of mainbeam power for location W (between Providence and Boston). This is the location on the high-altitude leg at which the lowest interrogator count was recorded. However, a relatively high (880 Hz.) suppression rate was measured there. At this site there were only four interrogators with mainbeam transmissions detectable above -50 dBm. One of these was Montauk Point, which does not employ sidelobe suppression. The other three were Boston Logan, Boston Winthrop and Quonset Point. The two Boston interrogators are known to employ 20 dB mainbeam-to-omni ratios based on the antenna patterns made during this flight. Since each of these interrogators transmits at approximately 400 Hz., and employs improved sidelobe suppression, together they account for most of the suppressions detected at this location. The Quonset Point interrogator does not employ improved sidelobe suppression. Its antenna pattern was not measured during the flight. However, its mainbeam was detected at a signal level of -45 dBm so that its suppression pulses also likely contributed to the total count at location W.

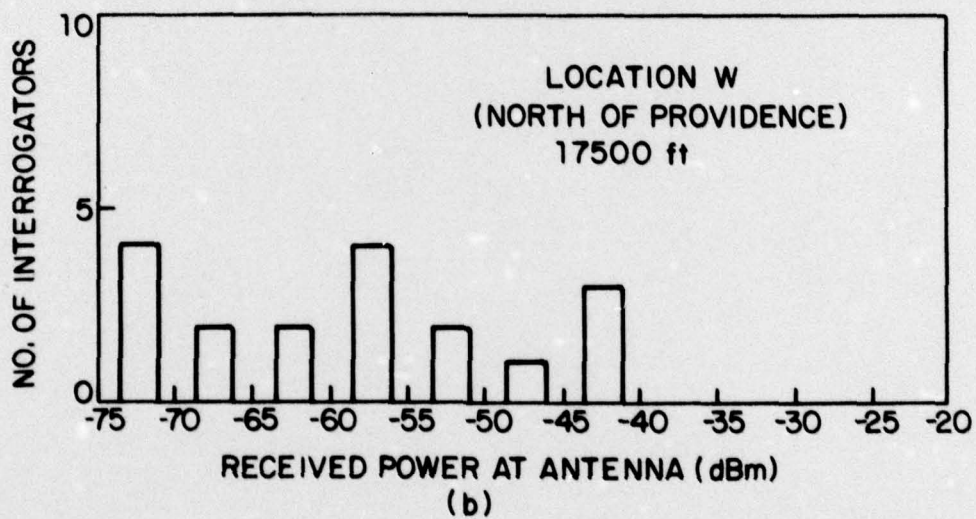
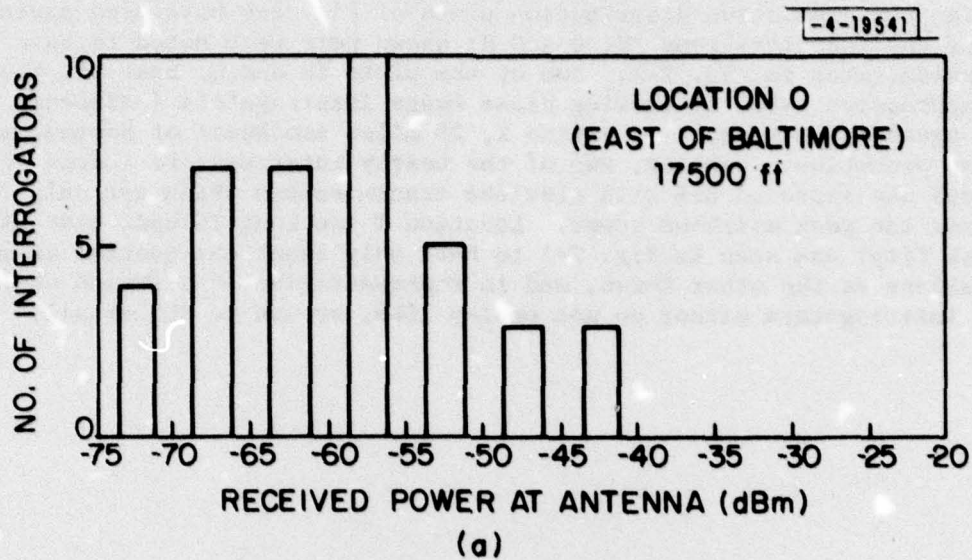


Fig.2-6. Number of interrogators detected with peak mainbeam power in each 5-dB amplitude interval over the dynamic range of the AMF.

Fig. 2-7 includes mainbeam power histograms for the four locations for which the cumulative distribution plots of Fig. 2-4 have been given. Three of the four locations (N, Q and X) shown here were noted to have high suppression rates in Fig. 2-1. Two of the plots (N and Q) bear out the high suppression rates by showing close range interrogators (mainbeam powers exceeding -40 dBm). Location X, 25 miles southwest of Boston, appears to be an exception. However, two of the nearby interrogators (Logan and Winthrop) use improved SLS with sidelobe transmissions which are only 20 dB down from the peak mainbeam power. Location T (on Long Island, east of New York City) was seen in Fig. 2-1 to have only about one-quarter as many suppressions as the other three, and is representative of a region where nearby interrogators either do not employ ISLS, or use no SLS at all.

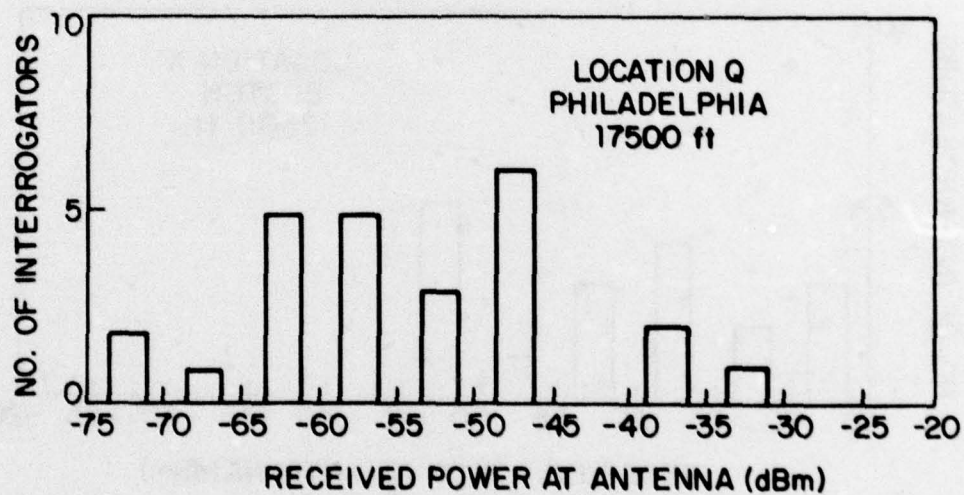
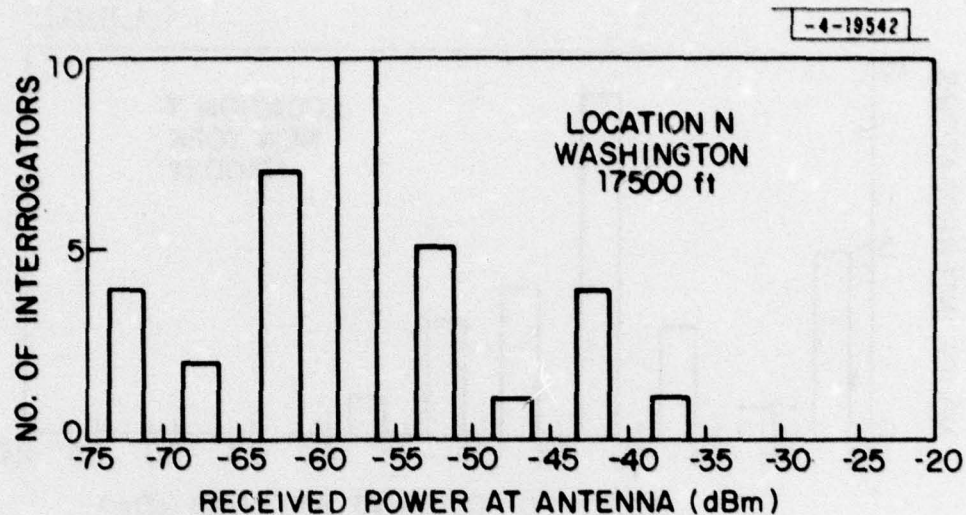


Fig.2-7. Number of interrogators detected with peak mainbeam power in each 5-dB amplitude interval for locations near the four major terminal areas.

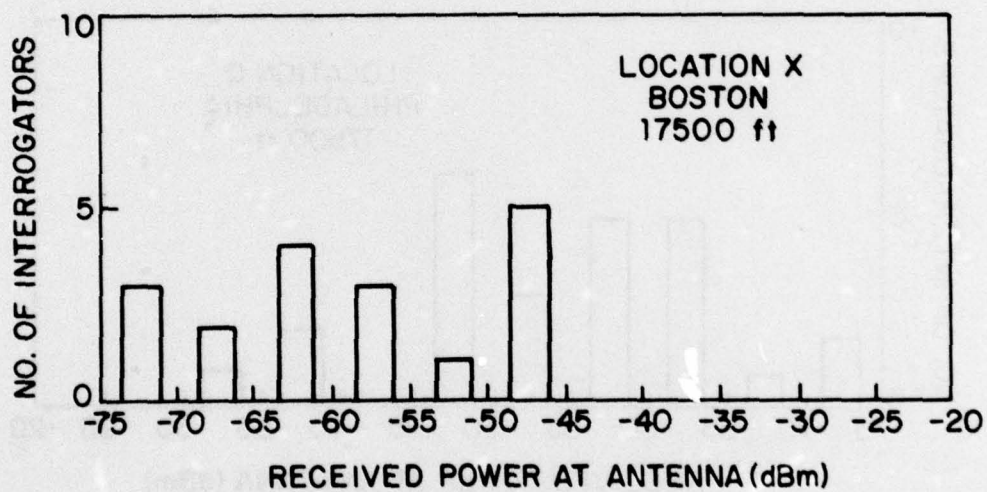
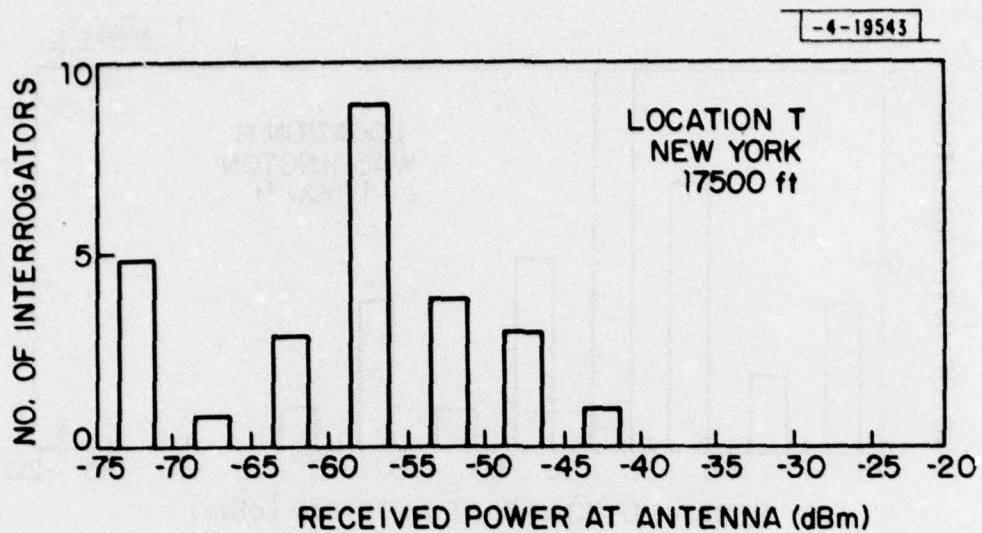


Fig.2-7. Continued.

3. SUMMARY OF THE UPLINK ENVIRONMENT IN THE NORTHEAST

Based on the measurements recorded at 24 locations from Boston to Washington, the ATCRBS uplink radiation environment in the northeastern part of the United States can be characterized as follows:

1. The most important contributors to the uplink pulse environment are omni-directionally radiated suppression pulses. The total pulse count and the suppression count are not closely correlated with aircraft altitude since omnidirectional transmissions are not detected at ranges greater than about 30 nmi. This also causes suppressions and total pulse counts to experience substantial variations along the flight path.
2. Suppression rates range from 150 per second to 1500 per second with an overall average suppression rate of approximately 600 per second. Suppression rates exceeding 1000 per second were recorded at 33% of the measurement locations, and rates of 400 per second or less were recorded at 38% of the locations. It is clear that at many locations, no more than a single interrogator contributes to the suppression environment, while there are other locations at which up to four or five interrogators with ISLS are detected.
3. Interrogation rates (as opposed to suppression rates) generally increase with altitude but are not strongly affected by proximity to known concentrations of interrogators. However, interrogation rates do increase significantly when the measurement is made in very close proximity to an interrogator without sidelobe suppression.
4. The average rate of receipt of Mode A plus Mode C interrogations over the entire flight path is approximately 75 per second at 8500 feet altitude and 100 per second at 17500 feet. The extremes of the combined Mode A and Mode C interrogation rates range from about 50 to 200 per second. Combined Mode A and Mode C rates exceeding 125 per second were recorded at 13% of the measurement locations and rates of 75 per second or less were recorded at 33% of the locations.
5. At most locations, the combined Mode 1 and Mode 2 interrogation rates remain insignificant (below about 20 per second). There are peaks in these rates near Baltimore, Philadelphia and Montauk Point, but the combined rate always remains below the Mode A and Mode C rates.